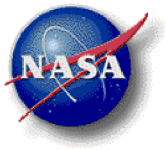

"Request for Information Response for the Flight Validation of Adaptive Control to Prevent Loss-of-Control Events"

Overview of RFI Responses

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August 2009

Response Overview

- RFI closed end of May 2009
- Over 20 responses received
- Good cross-section of community

Honeywell, MN

Zona Technologies, AZ

Univ. of Minnesota

CSA Eng., CA

Contek Res., OH

Boeing Corp, MO

Systems Technology, CA

NAVAIR

BAE Systems, NY

Calspan, NY

West Virginia Univ.

Scientific Systems Co., MA

Optimal Synthesis Inc., CA

GA Tech.

Pratt & Whitney, CT

Univ. of Michigan

F-18 IRAC RFI Response Summary

Key Technologies / Areas of Interest

– Integrated engine/aero surface control	(7 responses)
– Adverse pilot/controller interactions	(7 responses)
– Structures / structural modes	(6 responses)
– Metrics for evaluating adaptive controllers	(5 responses)
– Methods for V&V of adaptive systems	(5 responses)
– New analysis techniques for adaptive control	(5 responses)
– Autonomous vs. semi-autonomous recovery	(4 responses)
– Integrated adaptive inner- and outer-loops	(3 responses)
– Adaptive control in redundant architectures	(3 responses)
– Recovery from unusual flight conditions	(2 responses)

F-18 IRAC RFI Response Summary

Other Interesting Comments

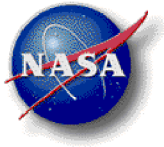
- Adaptive control should be integrated with a baseline controller and only used when necessary (5 responses)
- Implementation as an emergency system
  - Immediately re-stabilize and return to controlled flight
- Forced perturbation (excitation) for fine-tuning system
  - Check margins
  - Develop requirements for amplitude of excitation
- Adaptive system can improve performance by eating into margin constraints imposed on the non-adaptive system
- Nonlinear effects due to multi-string voting

F-18 IRAC RFI Response Summary

Other Interesting Comments

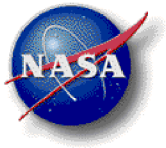
- It may be difficult to convince the aerospace community that results from a military fighter testbed are applicable to transport aircraft
- Lesson learned from VISTA: modifications to the functionality of the aircraft are doubly expensive due to the cost of recertification
- Evaluation metrics should include complexity of V&V and implementation

Verification and Validation



- "The usual elephant in the room is how to provide an airworthiness certification for an adaptive controller."
- Need for simplified adaptive system
  - Contrary to the "publish or perish" mindset
- Use augmentative control approach rather than full-scale substitution
- Monitor that assumptions used in stability proof remain valid
  - "Validation will have to include ensuring all the assumptions that adaptive guarantees are based on are in-fact met"

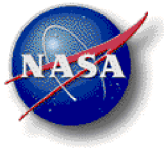
Obstacles



- “shortage of engineers with relevant adaptive control knowledge and experience”
- “scarcity of flight experiments using realistic platforms”
- Nonlinear time varying system
- Need Guaranteed Performance Adaptive Controllers
- Need meaningful performance objectives

Summary

- Thanks for the very good feedback
- This process will provide a high-payoff, high-quality flight experiment



"Request for Information Response for the Flight Validation of Adaptive Control to Prevent Loss-of-Control Events"

Experiment Classes

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August 2009

Full-Scale Flight Experiment

- Validate or Invalidate the “Imagined” problems
  - Those issues that can’t be convincingly answered in simulation or subscale testing

- “Real” world effects
  - Turbulence, gusts, wake encounter, etc.
  - Real sensor characteristics
  - Static structural constraints
  - Aeroservoelastic constraints
  - Interaction with pilot
    - Seat-of-the-pants feedback
    - High gain handling tasks
  - Aerodynamic uncertainties

- Added credibility for the methods that show the most promise

Adaptive Control Integrated with
Static Structural Constraints

- "The Super Hornet, even more than it's predecessor, has incorporated a number of tradeoffs between flying qualities and keeping structural loads in the box."
- Potential Experiments
  - Control within structural constraints
    - Ex: Fly same maneuver while reducing twist on one wing
  - Fiber optic shape sensors as "pain feedback"
  - Reconfigurable retrofit – drive adaptation through existing pilot input paths
  - LIDAR for gust load alleviation, wind shear / wake encounter mitigation
- Pluses
  - F-18 has real loads constraints
  - Much more tolerant to unexpected excursions
  - Highly instrumented for loads
- Concerns
  - Not a civil transport

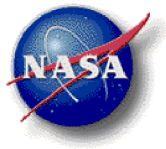
Adaptive Control Integrated with
Propulsion Control

- Potential Experiments
  - Slow responding effector integrated with faster aerodynamic control
  - Modify FADEC for
    - Quicker engine response mode for emergencies

- Pluses
  - Many controls including throttles that can be rate limited
  - Biggest benefit of adaptive control of engines is performance (economics) not safety (dual use)

- Concerns
  - Close coupled placement of engines
  - Changes to FADEC would be expensive
  - Lot of previous work done – are there really fundamental questions remaining?

Adaptive Control Integrated with
Aeroservoelastic Constraints



- Potential Experiments
  - Spatial sensing to eliminate structural modes from rigid body
  - Self-tuning notch filters
  - Study effect of interaction with high-gain adaptation
- Pluses
  - Existing notch filters could be faded out
    - Easy fail-safe reversion (turn filters back on)
      - Not immediately catestrophic
  - Very hard to model and accurately predict (makes good flight experiment)
  - Would provide much needed ASE model validation
  - Enabling technology for lighter structures
- Concerns
  - More sensors more potential failure modes
  - Need to manage the phase loss effect on rigid body control

Adaptive Control Integrated with
Pilot Interaction

- "at a very minimum the flight crew must be aware of the current state of the adaptive controller"
- Potential Experiments
  - Changing stick characteristics to inform pilot of degraded achievable performance
  - Provide gentile autopilot function that is can safely guide an extremely damaged vehicle (within very tight maneuvering constraints)
  - Develop pilot cues for remaining control authority
  - Develop emergency response and recovery system
    - "needs to be minimally invasive and take action only in the most dangerous circumstances when otherwise there would have been loss of control and eventual crash"
  - Investigate effect of an adaptive control system interacting with another adaptive system
- Pluses
  - Difficult to fully validate in simulation (makes good flight experiment)
  - Good handling qualities tasks
    - Air-to-air tracking
    - Formation flight
- Concern: Civil transport pilot interactions might be significantly different

Adaptive Control Integrated with
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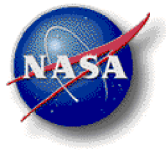

Your Thoughts?